

Challenges with Electrical, Electronic, and Electromechanical Parts for James Webb Space Telescope

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Abstract - James Webb Space Telescope (JWST) is the space-based observatory that will extend the knowledge gained by the Hubble Space Telescope (HST). Hubble focuses on optical and ultraviolet wavelengths while JWST focuses on the infrared portion of the electromagnetic spectrum, to see the earliest stars and galaxies that formed in the Universe and to look deep into nearby dust clouds to study the formation of stars and planets. JWST, which commenced creation in 1996, is scheduled to launch in 2018. It includes a suite of four instruments, the spacecraft bus, optical telescope element, Integrated Science Instrument Module (ISIM, the platform to hold the instruments), and a sunshield. The mass of JWST is approximately 6200 kg, including observatory, on-orbit consumables and launch vehicle adaptor. Many challenges were overcome while providing the electrical and electronic components for the Goddard Space Flight Center hardware builds. Other difficulties encountered included developing components to work at cryogenic temperatures, failures of electronic components during development and flight builds, Integration and Test electronic parts problems, and managing technical issues with international partners. This paper will present the context of JWST from a EEE (electrical, electronic, and electromechanical) perspective with examples of challenges and lessons learned throughout the design, development, and fabrication of JWST in cooperation with our associated partners including the Canadian Space Agency (CSA), the European Space Agency (ESA), Lockheed Martin and their respective associated partners. Technical challenges and lessons learned will be discussed.

Keywords: Electrical, electronic, James Webb Space Telescope, reliability, EEE, reliability, lessons learned, EEE Parts Engineer

1 Introduction

1.1 James Webb Space Telescope (JWST)

The James Webb Space Telescope is a space-based observatory. The three main JWST elements are the spacecraft, Integrated Science Instrument Module (ISIM), and the Optical Telescope Element (OTE). The Integrated Science Instrument Module (ISIM) contains the science payload comprised of four science instruments. The science instruments were developed with major contributions from

the European Space Agency, Canadian Space Agency and their respective contractors. Northrop Grumman provided the spacecraft.

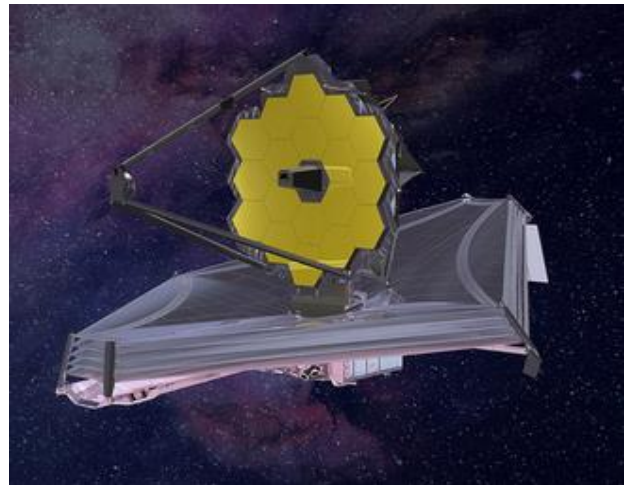


Figure 1. James Webb Space Telescope
(Artist Rendition Courtesy of NASA)

Table 1. JWST System and Main System Providers

<u>System</u>	<u>Main System Provider</u>
Mid-Infrared Instrument (MIRI)	European Space Agency (ESA), Jet Propulsion Laboratory (JPL)
Near-Infrared Camera (NIRCam)	University of Arizona
Near Infrared Spectrograph (NIRSpec)	NASA Goddard Space Flight Center (GSFC)/European Space Agency (ESA)
Fine Guidance Sensor (FGS)/Near InfraRed Imager and Slitless Spectrograph (NIRISS)	Canadian Space Agency (CSA)
Spacecraft Bus, Telescope, Sunshield	Northrop Grumman

1.2 Electrical, Electronic and Electromechanical (EEE) Parts

EEE (electrical, electromechanical, electronic) Parts, or component engineers, are responsible for selecting, providing, and managing EEE programs for NASA missions. This entails working with electrical and mechanical designers, procurement personnel, EEE part manufacturers, systems engineers, material engineers, and radiation engineers to ensure electronic components obtained are suitable for the mission application and duration. Types of components include resistors, capacitors, connectors, monolithic and hybrid integrated circuits, fuses, temperature sensors, magnetics, custom magnetics, transistors, diodes, wire, cable, and connectors.

2 JWST Challenges

2.1 JWST Programmatic Challenges

JWST posed several unique challenges:

- 1) The scope of EEE parts for JWST is > 6000 unique line items.
- 2) The program spans almost 20 years. Issues of obsolescence and design changes were constantly mitigated.
- 3) International Traffic and Arms Regulations (ITAR) and Export Administration Regulations (EAR) had to be managed with foreign partners, i.e. ESA and CSA, and their respective contractors and subcontractors.
- 4) The JWST NIRSpec instrument developed components for use at cryogenic temperatures, 38 K-40K (-235°C to -233°C).
- 5) EEE Parts problems averaged 1 every 6 weeks
- 6) Government Industry Data Exchange Reports (GIDEP) have to be addressed. They average 10 per month for EEE Parts. "GIDEP (Government-Industry Data Exchange Program) is a cooperative activity between government and industry participants seeking to reduce or eliminate expenditures of resources by sharing technical information essential during research, design, development, production and operational phases of the life cycle of systems, facilities and equipment."
- 7) NASA GSFC EEE Parts Analysis Lab directly handled 600 parts jobs over the past decade including screening, qualification, Destructive Physical Analysis, and Failure Analysis.

2.2 Reliability and Quality Level of EEE Components

JWST minimum mission life is 5 years with a goal to operate beyond 10 years. EEE components were selected with measures to achieve this goal. In the context of NASA Goddard Space Flight Center, this resulted in selection of Level 1 EEE Parts per the EEE-INST-002 Instructions for EEE Parts Selection, Screening, Qualification, and Derating. Level 1 parts are selected and processed for missions requiring the "*highest reliability and lowest level of risk.*" Level 1 is the highest reliability designation per the EEE-INST-002. Screening tests are performed with the intent of removing nonconforming parts (parts with random defects that are likely to result in early failures, known as "infant mortality") from an otherwise acceptable lot. Screening increases confidence in the reliability of the parts selected for use. Qualification testing is performed, consisting of mechanical, electrical, and environmental tests and inspections, and is intended to verify that materials, design, performance, and long-term reliability of the parts are consistent with the specification and intended application. Qualification also assures that manufacturer processes are consistent from lot to lot. Derating is the reduction of electrical and thermal stresses applied to a part during normal operation in order to decrease the degradation rate and prolong its expected life.

2.3 NIRSpec FPA and MSS Cryogenic Environment

The Near-Infrared Spectrograph (NIRSpec) was developed by the European Space Agency and EADS Astrium Germany GmbH (now Airbus Defence and Space Germany). It will be the first spectrograph in space with the capability to capture the spectra of ~ 100 objects simultaneously. The instrument operates in the wavelength range 0.6-5.3 μm . NASA Goddard developed the NIRSpec Focal Plane Array (FPA) and the NIRSpec Micro-Shutter Subsystem (MSS). The FPA contains two closely butted HAWAII-2RG HgCdTe sensor chip arrays (SCAs) and the SIDECARTM ASIC developed by Teledyne Imaging Systems (TIS).

NIRSpec's H2RG detectors operate at cryogenic temperatures. Unlike many other detector systems, critical segments of the FPA and MSS electronics were located in the detector thermal environment of 38K-40K to reduce noise. Electronics developed for military and space applications have a standard operating range of 125°C to -55°C (398K- 218K). The SIDECARTM ASIC and the HV584 (driver chip for the Microshutter Array) were two critical components developed to operate at JWST NIRSpec application temperatures. These assemblies were required to operate at room temperature and mission application cryogenic operating temperature while withstanding the rigors of being cycled from temperature extremes during component level ground testing through observatory

Integration & Test. This proved challenging for the circuit designers, system developers, and mission assurance team members to develop and prove the operational integrity and reliability of the system.

A listing of successfully mitigated problems:

- 1) High Voltage Driver Microcircuit (HV584) designed and developed for actuating Microshutters while operating at cryogenic temperatures
- 2) Attachment method and electrode optimization for surface mount ceramic capacitors to survive cycling from room temperature to cryogenic temperatures
- 3) SIDECAR ASIC development (Electronic System Miniaturization)
- 4) Package Development for SIDECAR™ ASIC

3 Qualification Challenges

3.1 SIDECAR™ ASIC

SIDECAR™ (System image, digitizing, enhancing, controlling, and retrieving) ASIC (Application Specific Integrated Circuit) is an electronic component developed by Teledyne Scientific & Imaging. The purpose of the SIDECAR™ for JWST is to manage all aspects of Focal Plane Array (FPA) operations and output digitization in three of the four science instruments.

The difficulty in qualifying the SIDECAR™ was based on several factors:

- 1) The ASIC application temperature for NIRSpec is 38K-40K. Closed cycle dewars can be utilized to achieve the thermal environment, however whenever dewar and resulting interfaces and instrumentation are involved, level of complexity, cost, and safety measures increase greatly for all entities involved in testing the component.
- 2) The behavior of electronics at temperatures below 77K (LN2 temperatures), especially over long term operation (i.e. > 5 years), are studied and understood by a small dedicated group of scientists, engineers, and researchers. With their assistance, and while juggling other JWST program priorities and SIDECAR™ ASIC assembly challenges, these issues were addressed throughout the program.[1]

SIDECAR™ ASICs received room temperature and cryogenic screening, numerous thermal cycles from room temperature to cryogenic temperatures, testing to determine

long-term behavior at cryogenic temperatures, destructive physical analysis at various stages of development, trend data analysis, and radiation testing to aid in qualifying the device for JWST long term operation.[2]

3.2 DC-DC Converters

DC-DC converters perform the function of power conversion, i.e. converting a 12V/1A supply to a 5V/0.5A supply to distribute power to subsystem electronic boxes and cards. This converter was a hybrid microcircuit, with discrete components enclosed in a single package. A DC-DC converter from a lot installed within a JWST instrument experienced a qualification test failure with potential impacts to mission reliability. Qualification occurs on units taken from the production flight lot. Flight units were already installed in hardware designated for final integration with the observatory.

A DC-DC Converter *Flight Worthiness* program was developed and implemented to address the issue. The multidisciplinary team included the ISIM Manager, Instrument Lead Engineer, Electrical Systems Engineers, EEE Parts Engineers, Failure Analysts, Reliability Engineers, Circuit Designer, part manufacturer team members and other key disciplines as needed.

After months of testing, analyses, and reviews, the DC-DC Converter was approved for Flight use in JWST. [3]

The decision was based on, yet not limited to:

- Qualification tests and analysis
- Destructive Physical Analysis (DPA)
- Mission Specific Application Testing
- Final Risk Reliability assessment

3.3 Operational Amplifier (Op-Amp)

Operational Amplifiers, also known as op-amps, are standard parts used throughout analog circuit design. They are used extensively across the JWST instruments. Bipolar Junction Technology (BJT) op-amps are used in instrument applications versus their Complementary Metal-Semiconductor Oxide Field Effect Transistor (CMOS) counterparts for their noise performance. Their disadvantage in space applications is they are more sensitive to the space radiation environment.

During research conducted after op-amp part installation into JWST flight hardware, it was discovered that an op-amp's radiation sensitivity level could be lower than expected due to a change in the package. Due to the gold content in the packaging of a dual op-amp, JWST had a risk of Single Event dielectric rupture damage. This Single Event Effect (SEE) could occur at a level of Linear Energy

Transfer (LET) of 15-20 MeV-cm²/mg for a ± 15 V supply setting vs onset between an LET of 40-44 MeV-cm²/mg for a ± 15 V supply.

Radiation Proton Beam testing was performed by NASA GSFC Radiation team (Code 561), at the Hampton University Proton Technology Institute and the Robert H. Lurie Comprehensive Cancer Center of Northwestern University . We were greatly fortunate to have received beam time at the respective universities thanks to the efforts of Ken Label/NASA GSFC Radiation Group Lead & Dr. Ray Ladbury/NASA GSFC Radiation Engineer.

Using the application worst case voltage levels of the op-amps, the team successfully confirmed that op-amps could safely be used in the JWST Instrument flight assembly. [4]

4 EEE & Assemblies Post Instrument Suite Cryogenic Vacuum Test

ISIM, the instrument suite and structure portion of JWST, completed its third and final cryogenic-vacuum test (CV-3) in late January 2016. ISIM will be integrated with the structure and optics. This system is called OTIS (Optical Telescope + ISIM) and will be undergo vibration and acoustic testing at NASA Goddard before moving on to NASA Johnson Space Center in Houston, Texas for optical testing in a cryogenic vacuum environment. Final integration with the spacecraft will occur at Northrop Grumman at Redondo Beach, California.

In an ongoing effort to mitigate any risks of EEE assembly failures greatly impacting the JWST schedule; the EEE assemblies, kits and material are stored in various sites through the country and Europe via support of the JWST program management team. Most are being tracked using the RFID (Radio Frequency Identification) technology to ensure periodic monitoring of the assets to be able to commence location and subsequent assembly and installation within weeks.

This process is another tool used to address the many challenges confronting the JWST EEE Parts Engineering Team.

5 Lessons Learned

Although there were numerous technical, programmatic, and management problems due to the complexity, scope, size, and duration of JWST, the team as a whole pulled together to see it through to the resolution of the problems.

A few lessons learned:

- 1) Problems do not go away overnight. Some problems took 1-3 weeks to resolve while other problems took years.

The goal is to stay the course, involve the needed team members, communicate, listen, decide and execute.

- 2) The biggest problems are the ones you do not know. The unexpected happens. Management leadership, and patiently establishing good communication with team members, provided a great foundation in enabling problem resolution.
- 3) Have Hope, Trust, and Keep Faith. JWST is the flagship observatory of this generation. The team encountered difficult problems and conflicting priorities but with faith, perseverance and dedication, team members were able to work towards a solution.

6 Conclusions

James Webb Space Telescope is a complex system. There were many challenges to deal with for EEE Parts. EEE Parts Engineers worked with the vast and dedicated JWST team to mitigate technical and non-technical issues.

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